Airborne Radio Echo Sounding on the Shirase Glacier and Its Drainage Basin, East Antarctica

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航空機搭載電波氷厚計による白瀬氷河およびその上流域の氷原と基盤地形調査

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要旨: 1980 年 1 月 29 日に，第 21 次南極地域観測隊が昭和基地に搬入，飛行を実施していたピラタスポーター機に電波氷厚計を搭載し，白瀬氷河およびその上流域で氷厚および基盤地形の調査を行った．使用周波数は 179 MHz，ピラタスポーター機の翼につけた三素子八木アンテナを使い送受信を行った．記録方式としては，反射エコー強度をオシロスコープ輝度に変換し連続的に反射エコーを記録するシステムと，飛行中 2.5 分ごとに A スコープ記録をとるシステムと 2 方式を採用した．なお，今回使用した電波氷厚計の場合 2000 m 以上の氷厚では，電波の減衰により，岩盤からの反射エコーはとらえることができなかった．

測定結果から，白瀬氷河下流域ではクレバスによるラジオ波散乱のため，明らかな岩盤からの反射は記録されず，白瀬氷河 B 地点 (70°20′S, 39°20′E) から約 30 km 上流部まで基盤は海面より高いところにあることがわかった．また，B 地点から上流 50 km までは，基盤地形は複雑であるが，それより上流部にはさほど複雑な地形はみられない．従前の C ルートと交わっている飛行経路上の点 (C94, C98) での氷厚は約 1600 m で，以前に地上から測られた電波氷厚の値に一致する．

Abstract: Airborne radio echo sounding carried out on the Shirase Glacier and its drainage basin in January 1980 is described. The new sounder (NIPR–A) was operated at 179 MHz on board a Pilatus Porter PC–6. Analysis of the continuous records of the sounding gave the bedrock topography along the flow line as well as in several cross sections of the downstream part of the glacier. The intense echo caused by the crevasses in the downstream masked that from the bed and so the depth and profile of the bedrock were obscured. In the lower part near point B (70°20′S, 39°20′E), the bedrock was partly below sea level. The bedrock topography 50 km upstream from B is complicated compared with that of the upper reaches of the Shirase Glacier drainage basin. The thickness of ice on the former C route taken by the traverse party in 1974 (C 94, 98) coincided well with the present results.

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1. Introduction

The Japanese Antarctic Research Expedition (JARE) carried out the survey of bedrock topography by means of radio echo sounding in Mizuho Plateau using SPRI (Scott Polar Research Institute) MKII Radio Echo Sounder with a 35 MHz transmitter several times between 1969 and 1974 (NARUSE and YOKOYAMA, 1975; OMOTO, 1976; SHIMIZU *et al.*, 1978). However, since the sounding was carried out only point-to-point from an over-snow vehicle on its traverse route, the survey was limited to the area where an over-snow vehicle can move, and also, as pointed out by MAE (1978), it was difficult to obtain correct profiles of the bedrock over a wide area. In order to avoid these defects of the sounding, the National Institute of Polar Research (NIPR) designed a new radio echo sounder (NIPR–A) which can be borne on a JARE aircraft, Pilatus Porter PC–6. Such an airborne radio echo sounder can provide consecutive areal data of the ice thickness with its continuous recording system.

The NIPR–A sounder was manufactured by Meisei Denki Co., Tokyo, in 1979. It was brought to Syowa Station, Antarctica by the 21st Japanese Antarctic Research Expedition (JARE–21) in January 1980 together with the Pilatus-Porter plane. The airborne radio echo sounding was carried out on the Shirase Glacier and its drainage basin, on the Yamato Mountains area and the route between Mizuho and Syowa Stations by the present authors (JARE–20) in cooperation with the JARE–21 members. In this paper, results of the sounding on the Shirase Glacier and its drainage basin are presented. No radio echo sounding of this area has been carried out before the present work.

2. Apparatus

The sounder consisted of a transmitter, a receiver, an aerial and an indicator. Specifications of each apparatus are listed in Table 1. Schematic diagrams of the transmitter and the receiver are illustrated in Figs. 1 and 2, respectively.

ROBIN *et al.* (1977) obtained simultaneous records by two radio echo systems operating at 60 and 300 MHz in West Antarctica and concluded that, while the clarity of the 300 MHz system was obvious, this system lacked the depth of penetration of the 60 MHz system because of increased absorption of radio waves by ice mass at the higher frequency. They suggested that if the problem due to the radio wave absorption could be overcome by increasing the power used in the high frequency system the advantage of the high frequency system would be obvious.

The SPRI MKII radio echo sounder used by JARE was operated at 35 MHz and its peak power was about 1 kW. JARE–20 carried out a radio echo sounding in Mizuho Plateau from an over-snow vehicle, SM–50, using the NIPR–V radio echo sound-

Table 1. Specifications of apparatus of NIPR–A sounder.

Transmitter	Carrier frequency Pulse energy duration Rise time Peak power Pulse repetition interval Total power consumption RF gain	179 MHz 0.3 μs 0.15 μs 1 kW 1 kHz DC 28 V, 2.7 A 39 dB
Receiver	Central frequency Band width Noise figure Receiver sensitivity Input attenuation	179 MHz 5 MHz 3 dB −104 dBm 0 to 70 dB in 10 dB steps
Aerials	3-element Yagi antenna Absolute power gain	 8 dB
Indicator (monitor and recorder)	Oscilloscope (National VP–5260) Rise time 35-mm continuous recording camera	 35 ns

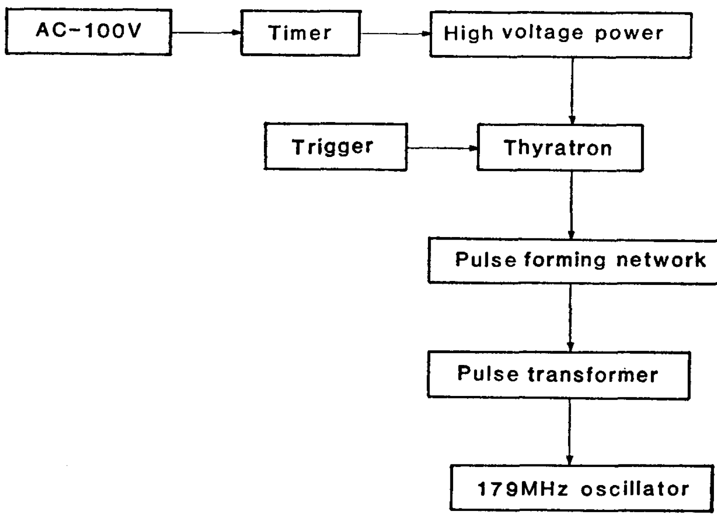


Fig. 1. Schematic diagram of transmitter.

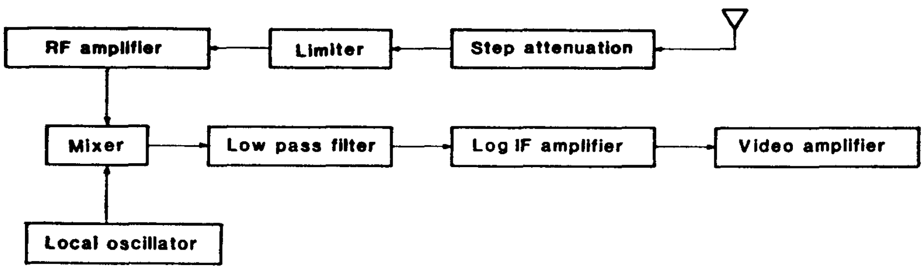


Fig. 2. Schematic diagram of receiver.

er which was operated at 60 MHz of which peak power was 1 kW. The penetration depth of both sounders was over 2000 m. However, the use of such a small aircraft as Pilatus Porter PC–6 involved two limitations; one is power supply and the other is short aerial length. In the case of the NIPR–A radio echo sounder, the maximum length of aerial attached to the wing of Pilatus Porter PC–6 was about 1 m as shown in Fig. 3 and the carrier frequency was determined to be 179 MHz. Since Pilatus Porter PC–6 can supply only 1 kW of electric power, the penetration depth of the radio wave of the NIPR–A sounder could not exceed 2000 m. However, it was expected that the sounder might be effective in the downstream area of the Shirase Glacier drainage basin where the ice thickness was less than 2000 m.

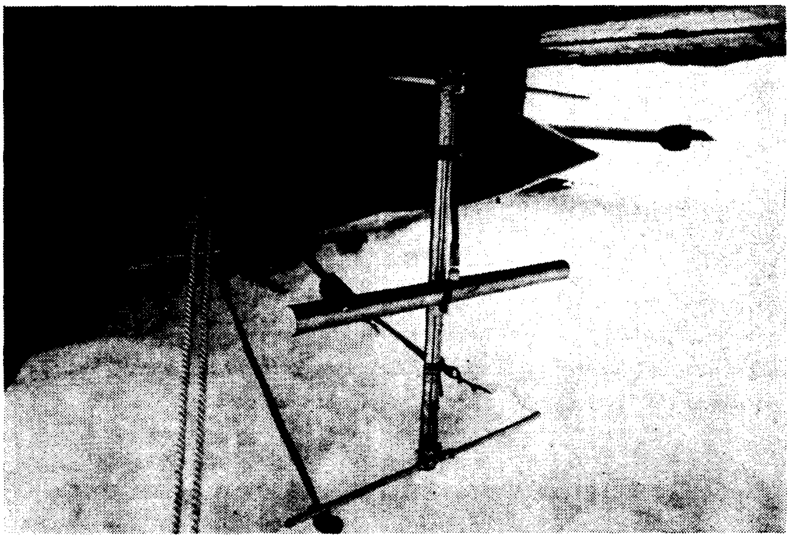


Fig. 3. 3-element Yagi antenna attached to wing of Pilatus Porter PC–6.

3. Region of Operation

The Shirase Glacier radio echo sounding was carried out on 29th January, 1980, along the flight route shown in a map of Fig. 4. Fig. 5 is an airphotograph of the Shirase Glacier viewed from the downstream. Unfortunately the navigation instrument of the aircraft to determine its position by detecting ω-wave did not work in this flight. Therefore, the flight route on the map was calculated from the direction and the speed of aircraft together with the flight time from the base points which are usually put on nunataks. The aircraft flew at a nearly constant height of about 3000 m and its total flight distance was about 800 km.

The flow line of the Shirase Glacier drainage basin is not clear yet, although it was drawn as shown in Fig. 4 by NARUSE and SHIMIZU (1978). Therefore, two long straight flight lines I and II to the inland area were selected in the direction of an approximate

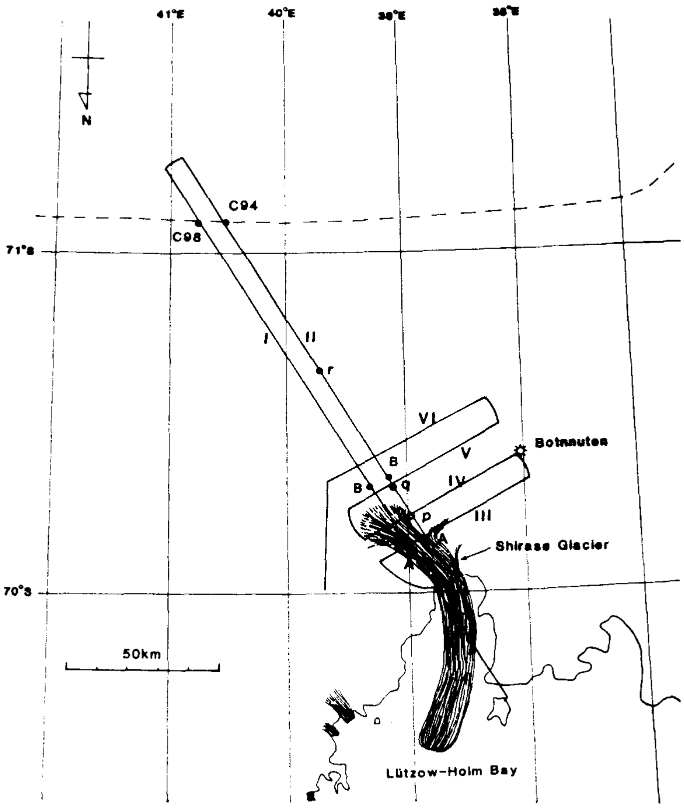


Fig. 4. Flight lines for radio echo sounding. A dashed line indicates C route (NARUSE and YOKOYAMA, 1975).

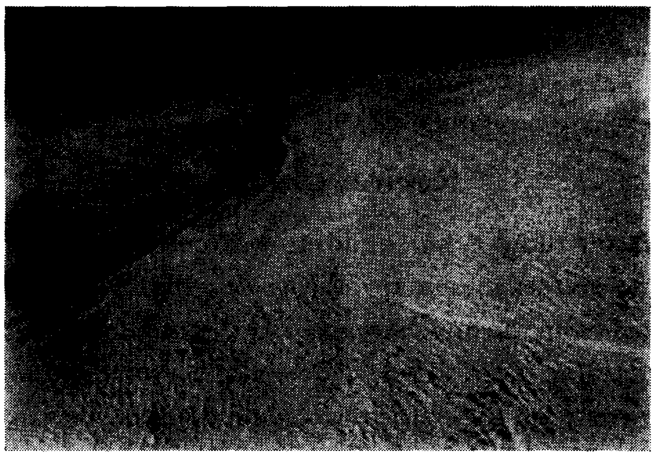


Fig. 5. The Shirase Glacier viewed from the downstream.

main stream. Flight lines III, IV, V, and VI, were selected perpendicular to the direction of I and II in order to see the cross section of the glacier.

4. Result and Discussion

Some parts of the continuous record along flight lines II and IV are shown in Figs. 6 and 7, respectively. From Fig. 6 it can be seen that no clear echo is detected between point A and B. The A-scope oscillogram of the echo intensity at points p, q and r in Fig. 6 is shown in Fig. 8 (a), (b) and (c), respectively. At point r, the echo intensity decreases rapidly as travelling time of echo increases and a clear echo reflected from the bedrock is observed. On the other hand, at points p and q the decrease in the echo intensity with the travelling time becomes slower than that at point r. Especially, at point p the echo reflected from the bedrock seems to be masked by the echoes caused by crevasses and cracks in ice mass, because the photographs from air and the Landsat satellite revealed those features in the downstream area of the Shirase Glacier.

The ice thickness is calculated from the echo time from the bottom using the value of wave velocity 169 m/μs in ice (ROBIN *et al.*, 1969). The bedrock topography thus obtained along flight lines I and II is shown in Fig. 9, and that along lines III, IV, V and VI is shown in Fig. 10. It can be seen from these figures that the bedrock topography is quite complicated. However, it can be concluded from Fig. 9 that the bedrock elevation is almost at the sea level until approximately 30 km inland from point B on the map of Fig. 4. Since Fig. 5 shows that the surface elevation of ice lowers considerably near point B and many crevasses are observed in the lower part of the glacier below B, it looks likely that this part of the Shirase Glacier is floating in the sea.

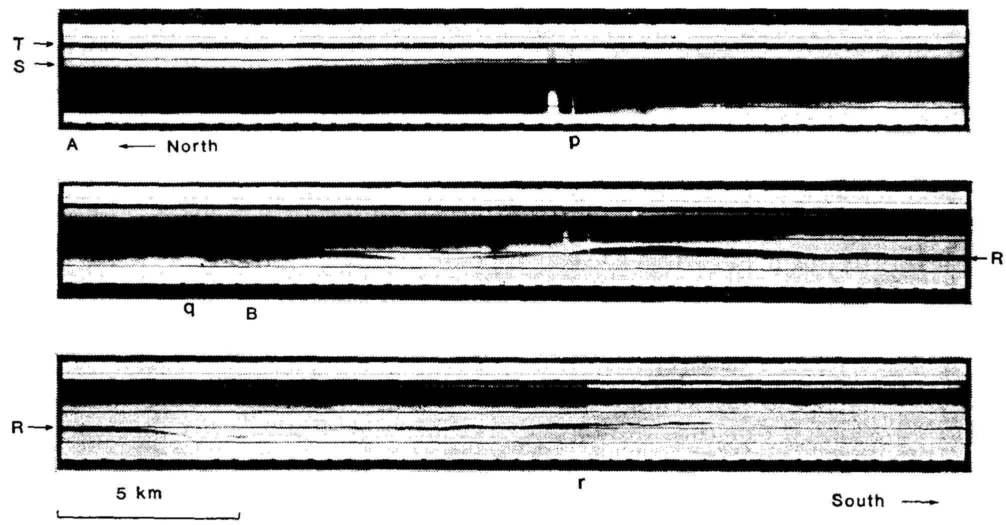


Fig. 6. Continuous record along flight line II. T, S and R indicate the position of transmitted wave, reflected wave from the ice surface, and reflected wave from the bedrock, respectively. Points A, B, p, q, and r are shown in Fig. 4.

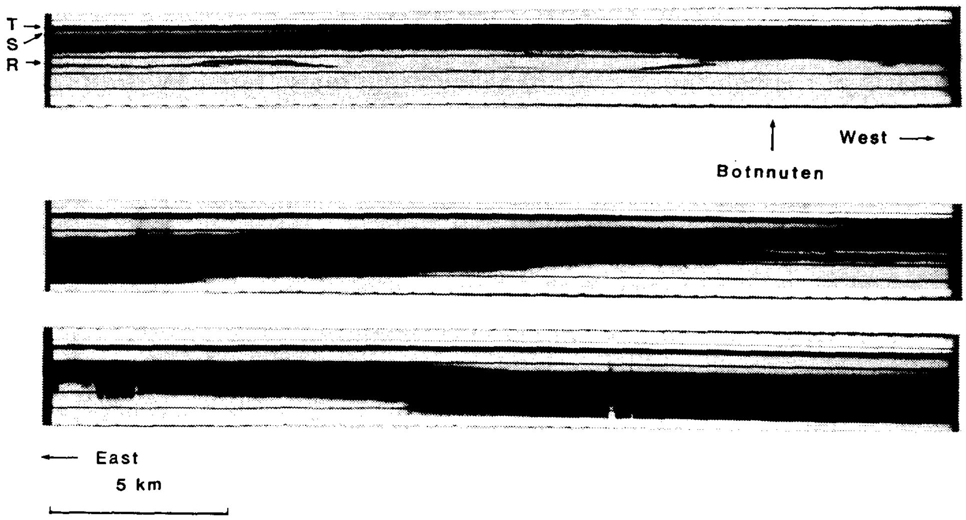
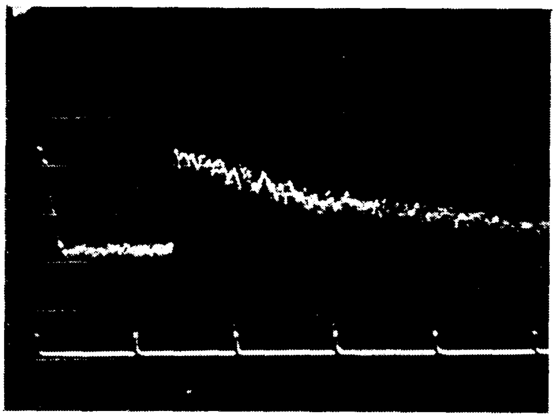


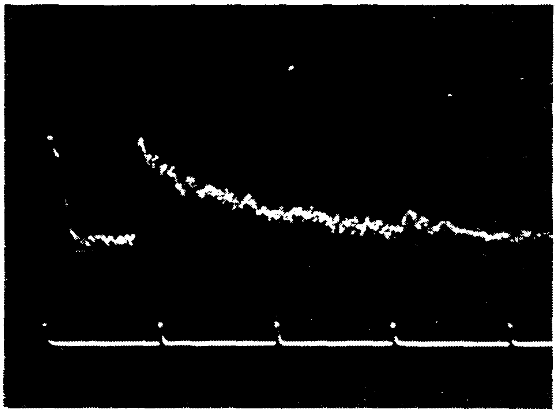
Fig. 7. Continuous record along flight line IV. An arrow indicates the west end of the line. T, S and R indicate the position of transmitted wave, reflected wave from the ice surface, and reflected wave from the bedrock, respectively.

Fig. 9 also indicates that the bedrock elevation is definitely higher than the sea level beyond approximately 30 km upstream of point B. Although there exist many undulations in the lower 30 km, the bedrock shape becomes smooth upstream. MAE (1978) drew bedrock topography along the S route which is nearly parallel to the flow line of the Shirase Glacier upstream, from the old data of point-to-point measurements of the radio echo sounding obtained by traverse parties. The results are consistent with those of the present work. As shown in Fig. 4, flight lines I and II crossed the former C route at C94 and C98, at a distance about 100 km from point B. The ice thickness obtained at C94 and C98 by NARUSE and YOKOYAMA (1975) was 1654 m which is approximately equal to the ice thickness at about 100 km shown in Fig. 9. Fig. 10 shows that the radio echo was very much obscured due to the scattering caused by crevasses in the lower part below point B, but in the section VI there appear images of mountain ridges (M and N).

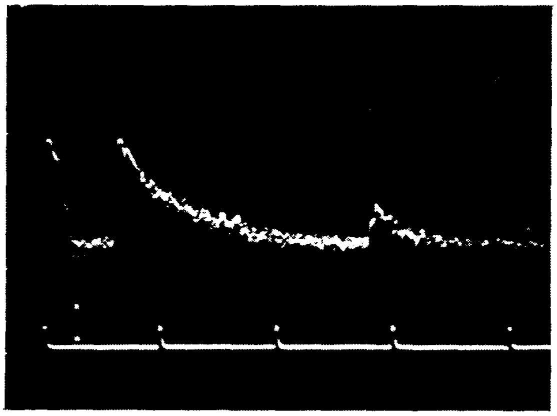
The fact that the bedrock elevation in the lower valley of the Shirase Glacier is below sea level implies that sea water can penetrate into the base of the ice body. This may enhance the glacier flow due to the basal sliding. MAE (1977, 1979) and MAE and NARUSE (1978) pointed out that the base of the Mizuho Plateau ice sheet might be wet and the basal sliding took place. However, it is difficult to determine the wet base from the results of the present investigation.



(a)



(b)



(c)

Fig. 8(a). A-scope record at point p.
(b). A-scope record at point q.
(c). A-scope record at point r.

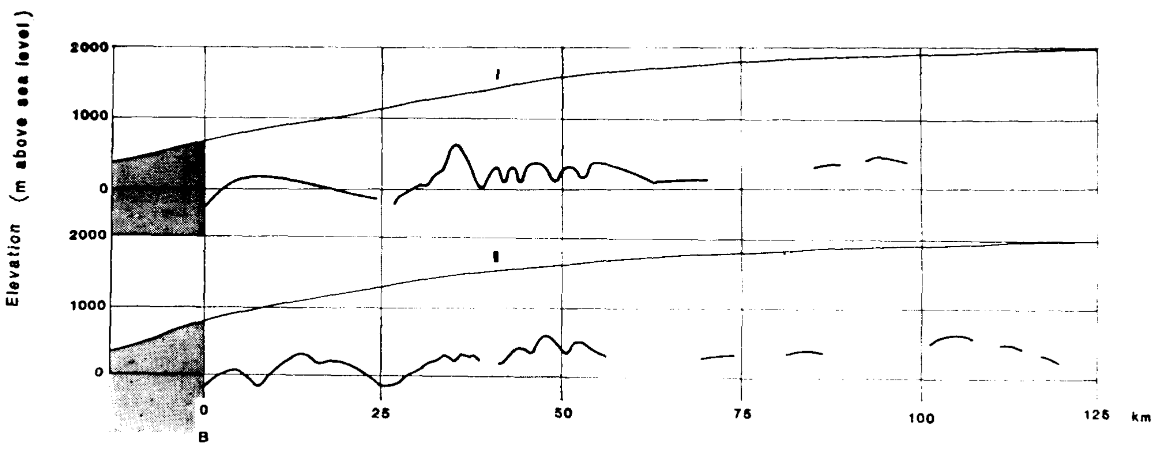


Fig. 9. Bedrock topography (thick lines) along flight lines I and II. Thin lines indicate ice surface.

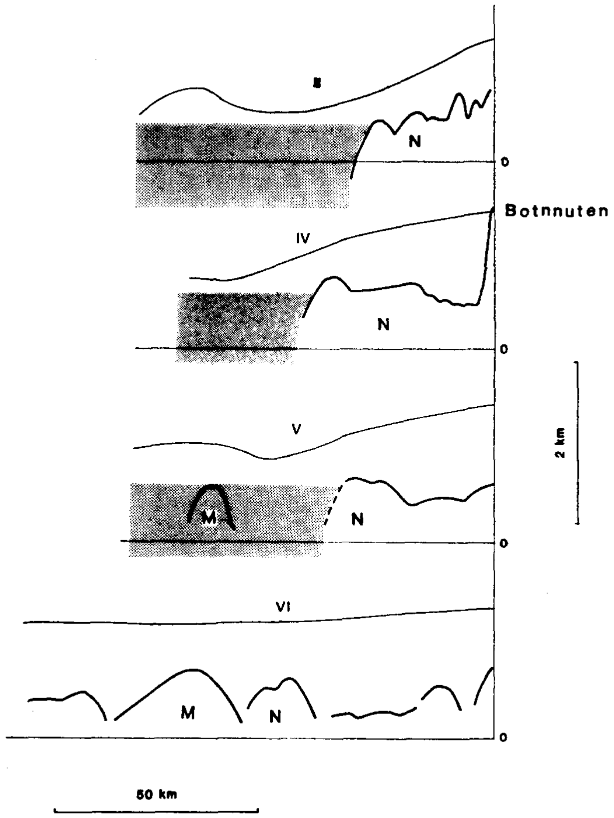


Fig. 10. Bedrock topography (thick lines) along flight lines III, IV, V and VI. Thin lines indicate ice surface. There appear images of mountain ridges (M and N).

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